Long Range Acoustic Propagation – Modeling and Data Analysis

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LONG-TERM GOALS

The long-term goals of this research are to understand the physical mechanisms that affect long range ocean acoustic propagation. Those mechanisms that are relevant to the deep-water Navy Anti-Submarine Warfare problem are of particular interest.   In addition to understanding acoustic propagation at long ranges, and local effects that can dominate the transmission of sound, we seek an understanding of the relevant oceanographic processes. This work concentrates on two particular physical processes. Firstly, the scattering of sound from the sea-floor in a as it propagates from the shelf (or island) to deep water. Understanding of this process is required for accurate understanding of the details of ocean ambient noise, as well as the prospect of localizing and detecting submarines either up the slope or down the slope from a reciever. The second effect is the scattering of acoustic energy by the sound speed fluctuations induced by internal wave motion of water column. Internal wave scattering effects are seen in a reduction of the coherence lengths in both time and space.

OBJECTIVES

Specifically, we are looking at the effect that the seafloor has on long-range tomographic signals sent during the North Pacific Acoustics Laboratory (NPAL) experiment. A 75-Hz source, with a Q of 2, was placed just off the sea-floor near the island of Kauai. Sound from the source propagates down the steep slope, into deep water and then across the Pacific to be received on the SOSUS network as well as on a set of 5 vertical line array receivers, located off Monterrey. The PI's for the NPAL experiment are Peter Worcester of Scripps Institution of Oceanography and Bob Spindel of the Applied Physics Laboratory – University of Washington.   It is our objective to understand the affect
That the presence of the sea-floor near the source has on the receptions taken many thousands of kilometers away.

APPROACH

The Ocean Acoustic Tomography Group, which uses the travel times of acoustic paths to invert for ocean sound speeds, has explicitly ignored interaction of sound with the bottom, stating as justification the fact that there exists a ray that goes up at the source, turns in shallow water and refracts into deep water without ever interacting with the bottom. This approach has been fruitful in many other experiments. In the NPAL dataset, however, the predictions of ray arrivals and the observed data do not match, making the identification of specific arrivals impossible. Our approach is two fold.   Using simulations, we study the effect that scattering with the sea-floor has on long range acoustic receptions.

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14. ABSTRACT

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WORK COMPLETED

We have shown that the mode scattering (reflections from the sea-floor) can lead to significant changes in the arrival time (and depth) of particular rays. The range averaged group velocity is required to compute the arrival time of a particular ray/mode and in the regions where the sound interacts with the bottom, the group velocities can be very, very slow.
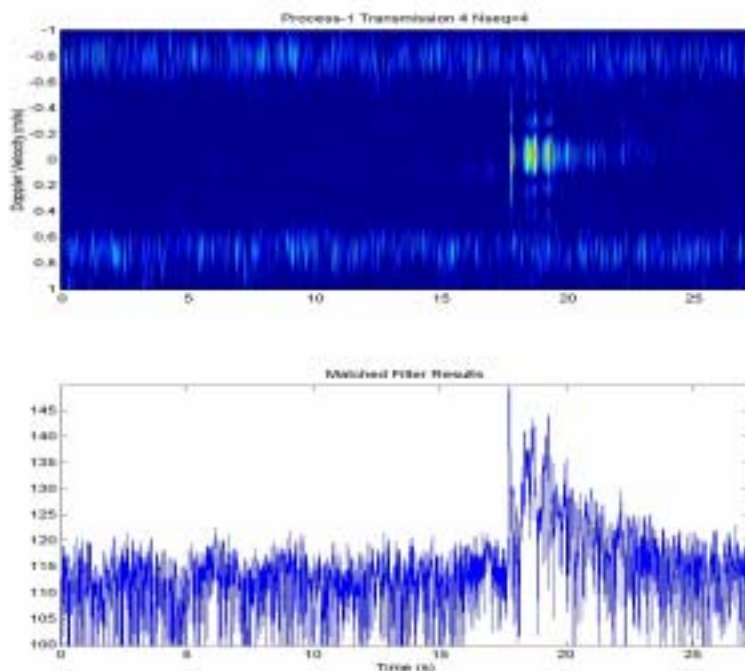
RESULTS

Dr. Heaney performed the Kauai Near Source Test (KNST) experiment designed to test the acoustic propagation near the Kauai source of the NPAL experiment. The purpose of the test was to examine the propagation from the source down the slope of the island shelf into deep water. NPAL researchers (at SIO and APL-UW) have discovered that acoustic energy is reaching the NPAL array network up to 1 second later than expected from ray-trace predictions. This deviation is far too large to be oceanographic in origin. Dr. Matt Dzieciuch has ruled out clock timing errors in the source and receiver. Dr. Heaney in the past has presented explanations of the delay being due to interaction with the sea-floor near the source (which is on the bottom). This test provides the opportunity to 1) check the source timing and 2.) look at propagation effects down the slope.

Eight recordings were taken on April 6th and April 10th off the coast of Kauai. An 8-element, 100m aperture Vertical Line Array (VLA) was deployed off of a small work boat (42' Huki-Pono, operated by Sea-Engineering, Honolulu). Array cable was purchased to deploy the array to a depth of 330m.The source transmits 27.18s m-sequences for 20 minutes (42 sequences after a ramp-up time) every 4 hours. To test the source timing as well as propagation effects, recordings were made at ranges of 200m, 3km, 5km, 25km, 38km, 55km and 128km. To facilitate accurate timing a GPS receiver was used with the signal recorded directly on the acoustic data using an IRIG-B format. The spectrum from a single phone of the VLA, taken at a range of 5km is shown in figure 1.
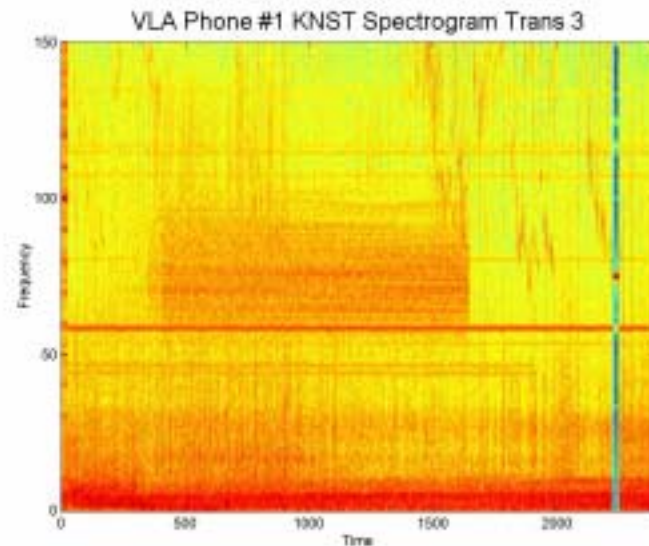

Figure 1. KNST Phone Spectra

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The signal is clearly visible from the 60-90Hz band from 500s to 1700s. The tone at 2300s is a 75Hz, 200mV calibration tone used to determine the absolute scale of the data.   The element data was matched filtered to produce time domain results. The match filter is doppler sensitive (up to 0.5 m/s) and therefore we searched over doppler to maximize the matched-filter response (and compensate for source drift). The matched-filter response for this phone is shown in figure 2.
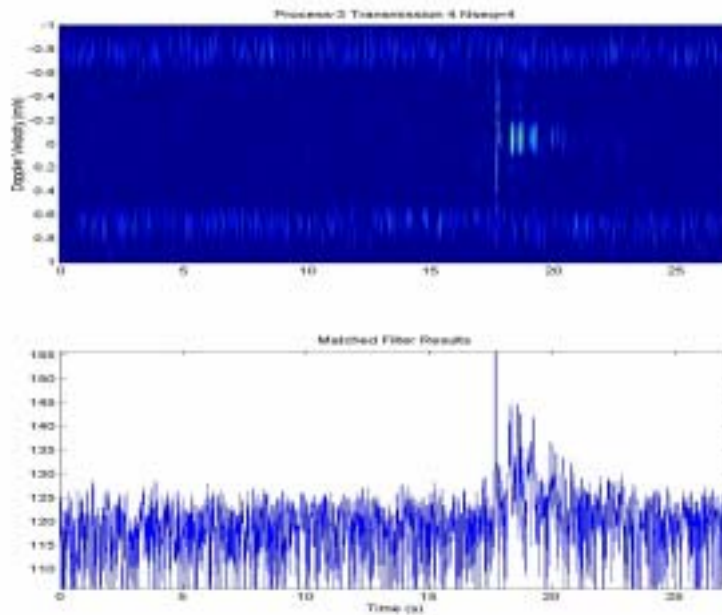

Figure 2. Matched Filter Results

At-sea a subset of the data was digitally recorded on a Macintosh and this is the data that we are presenting in this quick-look. The full 8-element VLA data was recorded on a DAT tape drive and will be examined over the next several months. The arrivals across a few of the hydrophone elements are shown in figure 3. This if for Transmission 2, which was at a range of 3km.
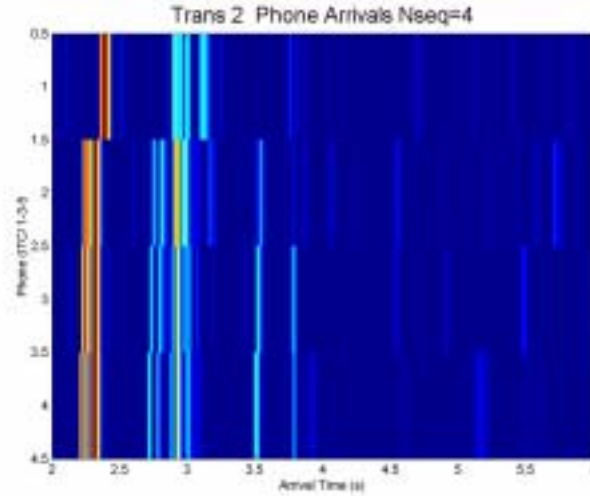
Figure 3. Time-series at 3km for single phone (near surface) and 3 elements of the VLA.

The recordings near the source show clearly that the source is going off at the correct time. PE predictions show that travel time from the source to 3km is 2.13 s, which is nearly that observed (2.25s). The interesting results are those at 25 and 55km. At 25.9 km (Transmission 4) the direct path is at it's lower turning point and therefore will pass below the array, which was deployed at a maximum depth of 400m. Anything we see will be due to interactions with the bottom. Arrivals at 25.9km are shown in figure 4.

Figure 4. Doppler and Matched Filter Results at 25.9 km.

There is clearly a strong dominant arrival followed by several other paths that we expect to be bottom interacting and will continue to interact with the bottom. The expected arrival time for a 1500 m/s group velocity is 17.2 s whereas 17.75s is the observed peak travel time. Parabolic Equation Modeling shows a dominant arrival (of the first bottom bounce) at 17.8s.

At 51.8km we are at the upper-turning point of the direct path and expect it to dominate the reception. There is indeed a clear arrival in this data.
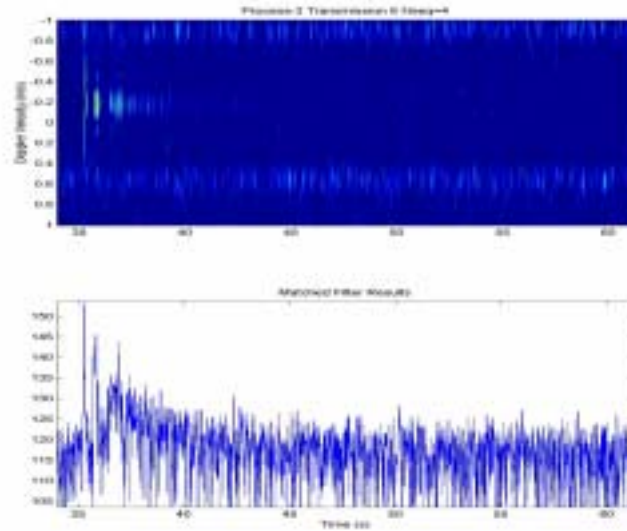
Figure 5. Reception at 51.8 km.

The predicted arrival time is 35.2 s for a group velocity of 1480 m/s and the observed time is 35.25s. We do not believe the array is deep enough to see the mode 1 energy.

One interesting observation from the data is to look at the received signal over the 20min. With significant SNR we are able to perform the matched filter on every individual sequence, providing us with 20 minutes of pulse arrival time series. Here is the result from Transmission 2.
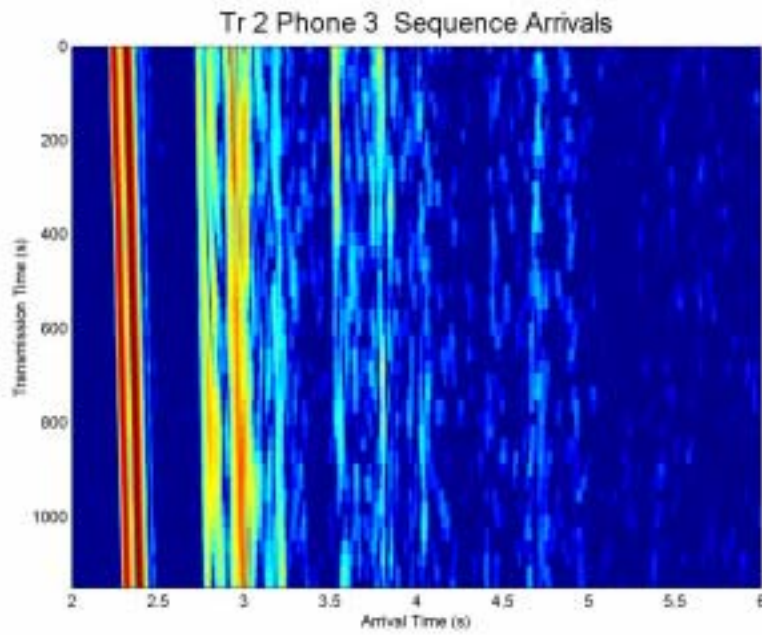
Figure 6. Arrival time variability over 20 min.

The direct path is the clear initial doublet (the surface reflection arriving a bit later). The nearly perfectly linear motion of the boat is clear in the acoustics, as it was also clear in the GPS data. The interesting result is the instability of the second doublet of arrivals; presumably they interact with the bottom once and the clearly unstable third and fourth pairs of doublets. The acoustic energy is interacting with different regions of the bottom over the 30s pulse-repetition-interval.

In terms of acoustics, it is clear that there is a strong bottom bounce entering the water-column (at angles that are low enough to limit future bottom interactions) as well as a strong direct path. The bottom bounce can account for the 0.5-1s delay that is observed. The presence of the equal strength direct path raises questions about where does it go.

IMPACT/APPLICATIONS

The impact of this research should be felt in two areas. Firstly, the ocean acoustic tomography community will need to use range-dependent full-field propagation models to understand the results that they are seeing. The area of ambient noise in deep water is also effected by these results. In particular, it is shown that high angle rays are converted into horizontally traveling rays, changing the vertical directionality of the noise field.

TRANSITIONS

Applications to the Submarine Security Program are being worked on. In addition to this, work is being done to build a Geo-Acoustics Inversion Toolbox with expected transition to the submarine fleet, the surface ASW and Air-ASW communities. The physical insight gained from studying the effects of downslope conversion on acoustics will lead to better tools for estimating geo-acoustic properties in range-dependent environments.

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